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# EVALUATING RETURNS TO RESEARCH IN PASTURE IMPROVEMENT*


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**The objectives of the study reported here were (a) to attempt to identify pasture research findings which have been important for the development of improved pastures in a number of agricultural regions, and (b) to estimate the internal rates of return on the investment in pasture research in these regions. The technique used was the estimation of input-demand functions for the stock of improved pastures. It is shown that the important research results were mainly the result of research in plant nutrition. Adoption lags were estimated, and these were short by comparison with those usually derived by other methods. Internal rates of return calculated for successful research findings were very high, but there were important differences between regions.**


The primary aim of this investigation was to estimate rates of return on investment in pasture research for a number of regions where the C.S.I.R.O. Division of Plant Industry has undertaken research. It was decided that, rather than estimating the benefits flowing from research by the usual residual methods [4, 6], the contribution made by individual research findings would be estimated. This approach raised the problem of identifying successful research findings. In an earlier study, Griliches [5] estimated the gains from an individually successful research project by means of an examination of the consequences of a shift of the product supply curve. This technique is not appropriate in the present circumstances, as the results of adopting new pasture technology are not directly observable in yield responses such as an increase in wool or beef. A means of estimating the benefits generated by an increase in the productivity of an input, in this case improved pastures, is suggested.

If the demand curve for an input is assumed to slope negatively, an increase in productivity will shift the curve to the right, as represented in Figure 1 by the shift from $ID_1$ to $ID_2$. Given certain assumptions, the hatched area represents the gross welfare gains from the increase in productivity.[1] It is the value of this area which is to be estimated.


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[1] It is assumed that product demand is perfectly elastic (or, as in the case of wool, most of any consumers' surplus accrues to overseas consumers), and the prices of all other inputs remain fixed. This latter assumption is necessary for determinancy in the derivation of input-demand curves. In the long-run it becomes

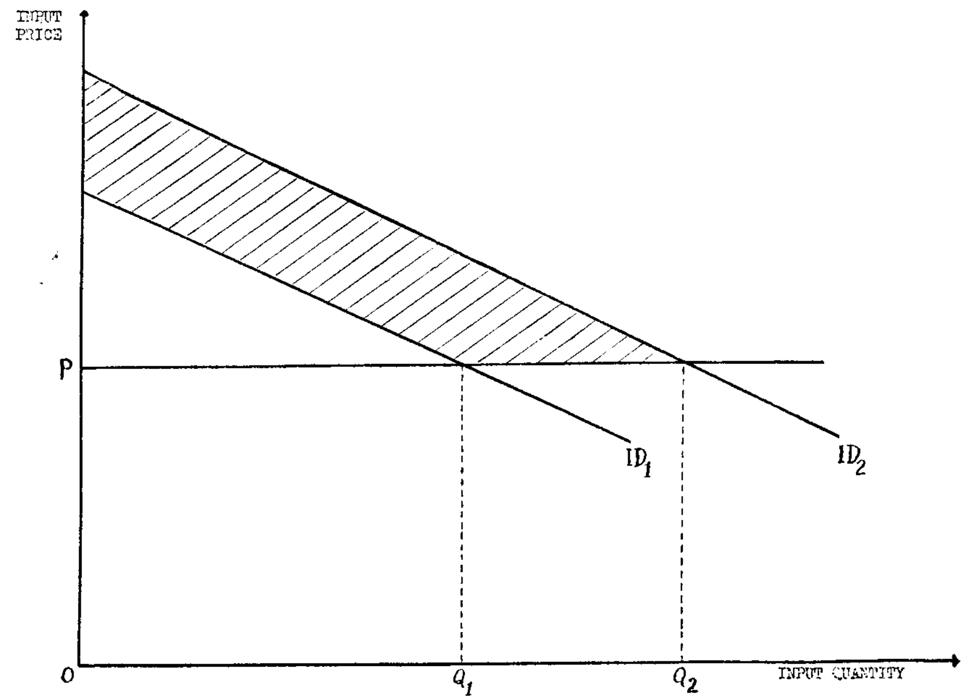


FIG. 1—The gains from an increase in the productivity of an input.

A single-equation regression model is formulated which is used to (i) estimate the own-price elasticity of demand for an input, and (ii) identify important research findings and estimate the increase in demand resulting from these, i.e., the shift from $Q_1$ to $Q_2$. A formula has been derived which uses these two pieces of information to calculate the gross value of the hatched area. In the model the area of improved pastures on farms in selected areas is treated as a durable input. The demand for the stock of this input is assumed to be a function of its real price and the state of pasture technology. Polynomial distributed lags are fitted to each of these independent variables to estimate the lags in adjustment of the stock associated with changes in factor and product prices and the state of pasture technology.

Possible changes in the state of pasture technology are identified with the announcement of seemingly important research results. The emphasis in the study is on the returns from research by the Division of Plant Industry. For each of the regions selected, all of the Division's research findings, which it was thought could have affected the demand for improved pastures, were tested in the model. In some regions however, research findings made by other public agricultural research organizations

a less tenable assumption. Figure 1 is based on a perfectly elastic supply for the input. For profit maximization to be operational it is necessary that at least one of the other inputs is less than infinitely elastic. This is usually true of land which is suitable for pasture improvement. Thus, much of the gain from new pasture technology will be capitalized into land prices. It is also assumed that the prices of other products which may be affected by an increase in output of the particular commodity are constant. In this sense the analysis is a partial equilibrium one. In particular, no attempt has been made to take account of the effects of productivity increases in one region of an industry on incomes of farmers in other regions.

were also tested. Internal rates of return are calculated on the costs associated with each successful research project, and on total pasture research and extension costs for each region.

Some dynamic aspects of the shift from $ID_1$ to $ID_2$ should be mentioned at this stage. First, the shift from $Q_1$ to $Q_2$ may not occur instantaneously. It seems, therefore, that the *long-run* elasticity of input demand is the relevant one. Second, the improvement in technology may erode over time (e.g., controls over plant and animal diseases and pests such as wheat rust and cattle tick may persist only as long as it takes for resistant strains of the organism to evolve). Third, while the productivity increase may continue into the future, the input-demand curve will change its position if product price changes, and this will change the size of the hatched area for a given improvement in technology. Estimation of the discounted value of future benefits therefore involves some prediction about product price.

## *The Model: The Demand for a Stock of Improved Pastures*

The model is a dynamic interpretation of the neo-classical theory of demand for an input. Static theory of the competitive firm assumes that the decision maker maximizes profits within a framework of known input-output relationships and price ratios, instant adjustment, and unlimited capital. Also, the individual's production decisions under perfect competition have no influence on prices. Within such a static framework it can be shown that changes in a firm's demand for an input will depend on (i) changes in the price of the product, (ii) changes in the cost of the input and in the cost of other inputs, and (iii) changes in the productivity of the input [13, pp. 187-9]. It is assumed that there is no money illusion and hence the demand function for an input is homogeneous of degree zero. This means that the demand for an input can be expressed as a function of real and relative prices.[2]

The demand for a durable input such as improved pastures is the demand for a capital stock which provides a flow of services. The purchase of durable inputs implies that the producer has a planning horizon which extends beyond a single production period. It seems likely, therefore, that he will attempt to maximize the sum of discounted future profits over this horizon rather than maximizing profits in each period. Jorgenson [7] shows that under certain assumptions the demand for the services of a durable input also depends on its real price and relative price. The services of durable inputs are usually not measurable, but, assuming that the flow of services is a constant proportion of the stock, it can be hypothesized that the demand for the stock of a durable input is also a function of its real and relative prices.

So we have,

$$K_t = f(P_{It}/P_{Pt},\ P_{It}/P_{Jt},\ R_t,\ u_t), \tag{1}$$

[2] Expression of the function in this form, while reducing the number of independent variables, does impose the constraint that the sum of the separate elasticities of demand (own price, cross price, and product price) should equal zero. It also raises the problem of the interpretation of the elasticity of a ratio, see Cowling *et al* [2].

where $K_t$ is the level of the stock of improved pastures at time $t$;[3] $P_{It}/P_{Pt}$ is the real price of the input at time $t$; $P_{It}/P_{Jt}$ is the relative price of the input (land was the only other input considered); $R_t$ is a shift variable denoting improvements in the state of pasture technology; and $u_t$ is an error term assumed to be random and uncorrelated with the independent variables. The relative price variable was dropped from the equation because of the ligh level of collinearity with the real price variable.

Prices, especially product prices, are uncertain in the planning period; therefore, some expectational assumption has to be introduced. In this case the simplest assumption has been made—that producers expect the immediate past prices to hold in the future.[4]

In order to introduce some dynamic aspects into the model the assumption of instant adjustment in the stock of improved pastures was relaxed. A lagged response in input demand to changes in new technology may be expected because the results of research take time to become widely known, and the reduction in the level of uncertainty associated with a new farming practice is probably largely a function of the number of producers adopting the practice. Possible changes in the state of pasture technology were identified with the publication of seemingly significant research results. Such research results were included in the input-demand equations as separate dummy variables. A value of 1 was assigned to all years following the year in which the research finding was announced. Polynomial lags [1] were generated on each of these variables to estimate the rate at which adoption took place. From the results it was then possible to calculate the incremental increases in the use of improved pastures resulting from the research finding. However, it is obvious that this specification can only give unambiguous results if the different research findings tested are separate in time.

A polynomial lag structure was also fitted to the real price variable. The equation to be estimated thus is equation (2) with the $w(i)$ as lag weights,

$$(2) \qquad lnK_t = b_o + \sum_{i=0}^{n-1} w_1(i) ln(P_I/P_{Pt})_{t-1} + \sum_{i=0}^{n-1} w_2(i) R_t + u_t.$$

The input-demand function was estimated with the variables expressed as logarithms. Thus the coefficients estimated on the price variables can be interpreted as geometric average elasticities of demand.

[3] A number of regions in which the C.S.I.R.O. Division of Plant Industry has done pasture research were defined in terms of Statistical Divisions. For each region the stock of improved pastures was measured in two ways: (i) the area of improved pastures (SP); and (ii) the amount of superphosphate used on sown and native pastures (SU). Generally, the SP series was found to be unsatisfactory because of the irreversible nature of this indicator of investment. The function estimated on the SU series is essentially a demand equation for superphosphate. However, this series does reflect farmers' desires to raise or lower the equilibrium level of the stock of improved pastures. Moreover, many of the improvements in pasture technology have been intimately linked to the use of superphosphate.

[4] In the woolgrowing areas studied, the product price used was the Australian average greasy wool price of the previous year ended 30th June. The price series used for improved pastures was the index of superphosphate prices. This fertilizer price index was used as a proxy for the cost of pasture improvement, as in the areas studied superphosphate is an important component of establishment costs and the most important component of maintenance costs. The use of the price of the durable input instead of its implicit rental assumes that the rate of depreciation and the rate of interest remain constant over time.

In fitting polynomial distributed lags, the degree of the polynomial, the length of lag and the 'tying' of end points has to be specified. In the absence of a specific behavioural hypothesis, polynomials of degree three and four were tried for the price variable, without any end points being tied. The lags in adjustment of $K_t$ in response to technological change were approximated by a polynomial of degree four, generally with the left hand end tied to zero. This seemed a suitable interpretation of the adjustment process as described above.

### *The Value of an Increase in the Productivity of an Input*

The *net* gain to society from an increase in the productivity of improved pastures is the value of the area ABCD in Figure 1, minus research costs, and minus any losses which result from market distortions due to subsidies, etc. These latter costs are ignored here on the basis that they are small for the wool industry. The following formula provides an estimate of the value of the area ABCD,[5]

$$b(Pe^{-Q_1/b} - Pe^{-Q_2/b}) - P(Q_2 - Q_1), \tag{3}$$

where $b$ is the long-run price elasticity of demand, and $P$ is the average cost of improving pastures during the time taken to move from $Q_1$ to $Q_2$. It is assumed that the shift from $ID_1$ to $ID_2$ relates to some input-demand curve based on an average product price for the period of the move from $Q_1$ to $Q_2$.

It is assumed that for most areas the cost of improving an acre of land to full productivity and maintaining it at that level is the initial costs of seed, fertilizer and cultivation plus the ad infinitum annual application of one hundredweight of supherphosphate. In order to get an annual value for the area ABCD, an acre of improved pasture is treated like a non-durable input with $P$ being the price of superphosphate in any year. It is assumed that the price of superphosphate after 1967-68 is the same as for 1968-69.

Some account must be taken of the very large fall in wool prices and the eroding effect which this has had on the benefits accruing from research. It was arbitrarily decided that the annual value of the benefits from an increase in productivity occurring before 1967-68 would, after that date, be reduced by one-quarter.

The annual costs per head for scientists employed by the Division of Plant Industry have been used for all estimates of research costs.[6] The year 1967-68 was chosen as the evaluation point for the purposes of calculating the internal rate of return.

### *Results*

Results from application of the input-demand model to three regions are presented below. The regions are: Northern Tablelands, N.S.W., Southern Tablelands, N.S.W., both wool growing areas, and the wheat/

[5] This formula was derived by integration. As the functions were estimated in double-log form, only constant elasticity shifts of the functions could be considered.

[6] The effect of price changes over time was accounted for by deflating a given proportion of expenditure (68 per cent) representing salaries and wages by an index of C.S.I.R.O. scientists' salaries, and the remaining expenditure was deflated by the Wholesale Price Index (1938-39 = 100). The superphosphate price index was also deflated by the Wholesale Price Index.

sheep zone in Western Australia. Internal rates of return have been calculated for research findings shown to have been important.

(i) Northern Tablelands, N.S.W.:

The C.S.I.R.O. began pasture research at Armidale in 1945-46. From the published results, three findings were chosen. These are: (i) report of significant effects of superphosphate, 1947-48; (ii) success in broad-

TABLE 1

*Estimated Equation: Demand for the Stock of Improved Pastures Northern Tablelands, N.S.W.*

| Independent Variables | | Dependent Variable $-ln(SU)$ | |
|---|---|---|---|
| Intercept | | 2·92 | |
| $ln(P_I/P_P)_{t-i}$ | $i=0$ | −0·71 (0·22)[b] | |
| | 1 | −0·32 (0·16) | −1·03[a] |
| Research Variable $(i)_{t-i}$ | $i=1$ | 0·42 (0·17) | |
| | 2 | 0·38 (0·11) | |
| | 3 | 0·32 (0·18) | |
| | 4 | 0·43 (0·18) | |
| | 5 | 0·63 (0·14) | |
| | 6 | 0·57 (0·16) | 2·74[a] |
| Research Variable $(iii)_{t-i}$ | $i=1$ | 0·38 n.s. (0·21) | |
| | 2 | 0·43 (0·19) | |
| | 3 | 0·33 (0·10) | |
| | 4 | 0·20 (0·09) | |
| | 5 | 0·13 n.s. (0·10) | |
| | 6 | 0·15 n.s. (0·08) | |
| | 7 | 0·23 (0·12) | |
| | 8 | 0·30 (0·11) | 2·14[a] |
| $\bar{R}^2$ (adjusted for degrees of freedom) | | 0·990 | |
| $d$ (Durbin-Watson statistic) | | 2·35 | |

[a] Sum of lag coefficients.
[b] Figures in parentheses are the standard errors of the estimated coefficients.
n.s. = Not significant.
Research Variable (i) = Reported 300 per cent increase in clover pasture yields with superphosphate, 1947-48.
Research Variable (iii) = Reported success with merino breeding on improved pastures, 1953-54.

casting clovers into natural pastures, 1951-52; and (iii) success with merino breeding on improved pastures, 1953-54.[7] The preferred equation for the estimation of the model for the 38-year period 1926-27 to 1940-41 and 1946-47 to 1968-69 is presented in Table 1. The SP and SU series were used as alternative measures of the level of the stock of improved pastures. However, only with the SU series as the dependent variable was the real price variable significant. The long-run elasticity of demand is —1·03 and adjustment takes only two years. The least-squares regression predicts the data very well including the downturn in superphosphate use after 1964-65.

Two of the three research variables included in the equation have significant lag coefficients. The upswing in pasture improvement on the Northern Tablelands began in 1948-49. If there was a big pay-off to research, beginning in this year, it could be argued that the Department of Agriculture should receive much of the credit. The work of the two organizations was probably complementary as they were doing research in different environments. However, there were other important innovations which took effect about this time and which have probably been captured in these two variables, viz., the development of suitable legume inoculum and the use of aerial sowing and topdressing.

For comparative purposes, an alternative specification of the input-demand function was also estimated. This was similar to a model which Metcalf and Cowling [9] used in estimating nitrogen fertilizer demand in the United Kingdom. The model used here was,

$$(4) \qquad lnK_t = b_o + \sum_{i=0}^{n-1} w(i) ln(P_I/P_P)_{t-1} + b_2 T + u_t.$$

In this formulation, $T$ is a variable representing time—a 'measure of ignorance' which attempts to capture all factors influencing productivity changes. The specification in equation (4) differs from the Metcalf and Cowling model in that they used the Koyck-Nerlove partial adjustment specification [14]. It is suggested that the direct estimation of the lag on the real price variable is less ambiguous in the sense that the lag is less likely to be a function of serial correlation in the data. The coefficients estimated with the SU series as the dependent variable are shown in Table 2. Equation (i) assumes instant adjustment, and equation (ii) is the result of fitting a lag to the price variable. The price variable coefficient in both equations is close to the estimate from Table 1. However, the Durbin-Watson statistic indicates a high level of autocorrelation. Correction for autocorrelation was carried out after estimating $r$, the coefficient in the first-order, auto-regressive error scheme. Equations (iii) and (iv) give the corrected estimates. Equation (iii) provides the more reliable results on the basis of its $d$ statistic. According to this equation the value of the real price elasticity coefficient is —0·58.

[7] The N.S.W. Department of Agriculture began experiments with sown, fertilized pastures in 1940 at Glen Innes [12]. In this first grazing experiment, the value of improved pastures to the health and production of dry sheep was demonstrated. In a follow-up experiment commencing in 1945 and continuing until 1954, the effect of improved pastures on sheep breeding was investigated. While these results preceded those by the C.S.I.R.O., the Department's work had no obvious impact on the use of improved pastures, at least until 1948-49.

TABLE 2

*The Demand for Superphosphate Fertilizer (Alternative Model) Northern Tablelands, N.S.W.*

| Independent Variables | Dependent Variable—$ln$(SU) | | | |
|---|---|---|---|---|
| | (i) | (ii) | (iii) | (iv) |
| Intercept | −0·27 | 0·36 | 0·13 | 0·05 |
| $ln(P_I/P_P)_{t-1}$ | −1·06 (0·32) | −0·86 (0·37) | 0·58 (0·23) | 0·11 n.s. (0·36) |
| $ln(P_I/P_P)_{t-2}$ | | −0·44 n.s. (0·31) | | |
| $T$ | 0·24 (0·01) | 0·22 (0·01) | 0·05 (0·008) | 0·06 (0·008) |
| $\bar{R}^2$ | 0·935 | 0·945 | 0·64 | 0·73 |
| $d$ | 0·46 | 0·49 | 1·52 | 1·27 |
| $r$[a] | 0·79 | 0·76 | | |

[a] $r$ is the estimated coefficient in the first order, autoregressive scheme $\hat{u}_t = r\hat{u}_{t-1} + e_t$, which is estimated on the least-squares residuals.

The evidence suggests that the real price elasticity coefficient is not large, pointing to the conclusion that it was not primarily the high wool prices making pre-war research results more profitable which caused the big upswing in pasture improvement. The results suggest that the upswing was mainly due to research findings which occurred during the period of high prices—when we would expect innovations to be most profitable. The argument that the increase in improved pastures was primarily due to the adoption of old pasture technology in a period of high on-farm liquidity is also suspect. This reasoning implies that even though pasture technology was known to be profitable, capital limitations both within and without the rural sector were such as to prevent *any* investment taking place.

The gross benefits from the two research variables in Table 1 were calculated using the formula given above. As the regressions were estimated in double-log form the value for $Q_1$ was, in each case, taken to be the geometric average of superphosphate use for the period over which the regressions were estimated. The value for $Q_2$ in each year was thus the sum of lag coefficients in that year times the geometric average for superphosphate use. The annual benefits yielded by the two research variables up to 1968-69 are shown in Table 3. Two sets of figures are presented to demonstrate the sensitivity of the benefits yielded to the size of the price elasticity of demand for the input. The elasticity value of −1·03 is from Table 1, and the value of −1·30 is from Table 2.

It was suggested that if the two research variables do in fact measure the contribution of the two research findings tested, the credit for these is shared by the N.S.W. Department of Agriculture. The research cost estimates were made on this basis. Two cost estimates have been derived. The first estimate includes only those projects of the C.S.I.R.O. at Armidale and the Department of Agriculture at Glen Innes which would have directly contributed to the two research findings. The second

TABLE 3

*The Gross Benefits from Pasture Research Northern Tablelands, N.S.W.*

| Year | Research Variable (i)[a] | | Research Variable (iii)[b] | |
|---|---|---|---|---|
| | Price Elasticity (−1·03) | Price Elasticity (−1·30) | Price Elasticity (−1·03) | Price Elasticity (−1·30) |
| | ($'000) | ($'000) | ($'000) | ($'000) |
| 1948-49 | 379 | 201 | | |
| 49-50 | 708 | 374 | | |
| 50-51 | 1,012 | 535 | | |
| 51-52 | 1,416 | 749 | | |
| 52-53 | 1,998 | 1,056 | | |
| 53-54 | 2,529 | 1,337 | | |
| 54-55 | 2,529 | 1,337 | 223 | 128 |
| 55-56 | 2,529 | 1,337 | 472 | 270 |
| 56-57 | 2,529 | 1,337 | 658 | 377 |
| 57-58 | 2,529 | 1,337 | 769 | 441 |
| 58-59 | 2,529 | 1,337 | 844 | 483 |
| 59-60 | 2,529 | 1,337 | 931 | 533 |
| 60-61 | 2,529 | 1,337 | 1,067 | 611 |
| 61-62 | 2,529 | 1,337 | 1,241 | 711 |
| 62-63 | 2,529 | 1,337 | 1,241 | 711 |
| 63-64 | 2,529 | 1,337 | 1,241 | 711 |
| 64-65 | 2,529 | 1,337 | 1,241 | 711 |
| 65-66 | 2,529 | 1,337 | 1,241 | 711 |
| 66-67 | 2,529 | 1,337 | 1,241 | 711 |
| 67-68 | 2,529 | 1,337 | 1,241 | 711 |
| 68-69 | 1,897 | 1,003 | 931 | 533 |

[a] $P_t$ = $8.00 per ton for superphosphate fertilizer.
[b] $P_t$ = $7.73 per ton for superphosphate fertilizer.
The geometric average of the SU series over the period 1937-38 to 1968-69 was 9,850 tons.

estimate represents total pasture research by the two organizations up to the end of the second period of adjustment, 1960-61.[8] The internal rates of return calculated on these alternative research cost streams are shown in Table 4.

TABLE 4

*Internal Rates of Return on Pasture Research Northern Tablelands, N.S.W.*

| Research Cost Streams | Input Demand Elasticity | |
|---|---|---|
| | −1·03 | −1·30 |
| | (%) | (%) |
| Individual Projects only | 80 | 65 |
| Total Pasture Research and Extension | 68 | 58 |

[8] Costs up to the end of the adoption period were included on the basis that research after the publication of the findings would be aimed at influencing the transmission of the results. This may also be thought of as including a component of expenditure for regional extension.

(ii) Southern Tablelands, N.S.W.:

Three research findings from the Division's work at Canberra were tested in the model. These were: (i) first reports on successful establishment and response of subterranean clover to surface cultivation and superphosphate, 1940-41; (ii) reports of success with clover nodulation problems through use of molybdenum and lime, 1947-48; and (iii) use of lime-pelleting of clover seed in acid soils, 1954-55.

As shown in Table 5, the research findings relating to the use of molybdenum and lime, and lime-pelleting of clover seeds were important in explaining increases in superphosphate use. Only in those equations where the price variable was not lagged was its coefficient significant.

TABLE 5

*Estimated Equation: Demand for the Stock of Improved Pastures Southern Tablelands, N.S.W.*

| Independent Variables | | Dependent Variable $-ln(SU)$ | |
|---|---|---|---|
| Intercept | | 5·19 | |
| $ln(P_I/P_P)_{t-i}$ | | −0·55 (0·17) | |
| Research Variable $(ii)_{t-i}$ | $i=1$ | −0·05 n.s. (0·09) | |
| | 2 | 0·04 n.s. (0·08) | |
| | 3 | 0·18 (0·05) | |
| | 4 | 0·29 (0·06) | |
| | 5 | 0·33 (0·07) | |
| | 6 | 0·27 (0·06) | 1·08[a] |
| | 7 | 0·12 n.s. (0·13) | |
| Research Variable $(iii)_{t-i}$ | $i=1$ | 0·34 n.s. (0·33) | |
| | 2 | 0·47 n.s. (0·42) | |
| | 3 | 0·47 n.s. (0·36) | |
| | 4 | 0·39 n.s. (0·24) | |
| | 5 | 0·28 (0·13) | |
| | 6 | 0·18 (0·07) | 0·46[a] |
| | 7 | 0·10 n.s. (0·06) | |
| $\bar{R}^2$ | | 0·97 | |
| $d$ | | 1·74 | |

[a] Sum of significant lag coefficients.
Research Variable (ii) = Use of molybdenum and lime to overcome clover nodulation problems, 1947-48.
Research Variable (iii) = Use of lime-pelleting of clover seeds in acid soils, 1954-55.

The alternative model was also estimated, and the results were:

$$ln(\text{SU}) = 1{\cdot}46 - \underset{(0{\cdot}17)}{0{\cdot}36}\, ln(P_I/P_P)_{t-1} + \underset{(0{\cdot}006)}{0{\cdot}028}\text{T} \qquad \bar{R}^2 = 0{\cdot}57 \quad d = 1{\cdot}49 \quad r = 0{\cdot}71$$

after correction for positive, first-order serial correlation.

On the basis of the results in Table 5, the gross benefits generated by research variable (ii) up to 1967-68 were calculated at \$3·0 million. At a price elasticity of —0·36 (from the alternative model) total gross benefits to 1967-68 were \$5·6 million. The gross benefits generated on research variable (iii) up to 1967-68 were \$0·5 million, given a price elasticity of —0·55, and \$0·94 million, given a price elasticity of —0·36. On research costs of two scientists per year from 1943-44 (when plant nutrition studies began at Canberra) to 1961-62 (the end of the lag on research variable (iii)) the internal rates of return calculated for the combined stream of benefits were as follows: 53 per cent when the price elasticity was —0·55; and 67 per cent when the price elasticity was —0·36. If it is assumed that these two research variables captured most of the contribution by pasture research in the area, a rate of return on total pasture research expenditure can be calculated. A conservative

TABLE 6

*Estimated Equations: Demand for a Stock of Improved Pastures . .*
*(Instant Adjustment Model)*
*Wheat-Sheep Zone, Western Australia*

| Independent Variables | Dependent Variable—$ln$(SU) | | | |
|---|---|---|---|---|
| | (i) N.A.D.[a] | (ii) C.A.D.[a] | (iii) S.A.D.[a] | (iv) Total |
| Intercept | 4·28 | 5·40 | 5·67 | 6·39 |
| $ln(P_I/P_P)_{t-1}$ | —0·15 n.s. | —0·30 n.s. | —0·08 n.s. | —0·22 n.s. |
| | (0·16) | (0·20) | (0·14) | (0·15) |
| RV (i) | 0·85 | 0·70 | 0·90 | 0·77 |
| | (0·13) | (0·20) | (0·12) | (0·13) |
| RV (ii) | 0·51 | 0·48 | 0·31 | 0·44 |
| | (0·16) | (0·17) | (0·13) | (0·14) |
| RV (iii) | 0·40 | 0·34 n.s. | 0·29 | 0·45 |
| | (0·18) | (0·19) | (0·15) | (0·17) |
| RV (iv) | 0·42 | 0·23 n.s. | 0·20 n.s. | 0·22 n.s. |
| | (0·15) | (0·16) | (0·12) | (0·14) |
| RV (v) | 0·80 | 0·48 | 0·32 | 0·52 |
| | (0·18) | (0·18) | (0·13) | (0·14) |
| $\bar{R}^2$ | 0·98 | 0·96 | 0·97 | 0·97 |
| $d$ | 2·10 | 1·33 | 1·20 | 1·67 |

[a] N.A.D. = Northern Agricultural Division, W.A.
C.A.D. = Central Agricultural Division, W.A.
S.A.D. = Southern Agricultural Division, W.A.

*Research Variables*

RV (i) = 'Light lands' improvement recommendations, 1945-46.
RV (ii) = Clover-ley system for 'light lands', 1950-51.
RV (iii) = Lime-pelleting legume seeds, 1956-57.
RV (iv) = Release of Cyprus Barrel medic, 1961-62.
RV (v) = Molybdenum deficiency on 'light lands', 1965-66.

estimate for pasture research expenditure in the region by the Division and the N.S.W. Department of Agriculture was four scientists per year from 1937-38 to 1961-62. The internal rates of return calculated on this cost stream, given price elasticities of —0·55 or —0·36, were 22 per cent and 27 per cent respectively.

(iii) Wheat/Sheep Zone, Western Australia:

The wheat/sheep zone of W.A. was taken to be that area comprised of the Northern, Central, and Southern Agricultural Divisions. Pasture research by the Division of Plant Industry in W.A. (begun in 1938-39) has been closely linked with that of the W.A. University's Institute of Agriculture and the W.A. Department of Agriculture. Consequently, it is difficult to ascribe particular findings to individual organizations. For this reason, all research findings which may have been important to pasture improvement in this region were tested in the model. The model was estimated on the SP and SU series for the three Agricultural Divisions separately as well as conjointly. If it could be expected that some of the research findings would be more likely to be adopted in one or other of the regions, it was felt that this would provide a test of the model.

Six research findings were chosen for testing, but not all of these could be put into the estimated equation because of the programming restriction on the number of variables which could be lagged (four only). Interpretation of the results was, therefore, somewhat confounded. After testing all of these research findings in the model, singly, in pairs, and in threes, three were found to be consistently insignificant.[9] It was decided to put all of the research findings into one equation and estimate it without lags, i.e., assume instant adjustment to changes in technology. The results from this exercise, shown in Table 6, in no way contradicted those from the lagged model. The same research variables were always insignificant.

It is of interest to compare the results in Table 6 with some of the results from the lagged model. Table 7 presents, for the three divisions, estimated equations which include research variables (i) and (iv).[10]
Table 8 presents results for equations which include research variables (i) and (v). Research variable (i) was included in both lagged regressions because it was the most important influence, and in the lagged model seemed to dominate research variable (ii). A comparison of the results in the three tables shows that, with one exception, the same orderings and the same orders of magnitude are maintained within and across the three divisions for research variables (iv) and (v).

These results are also consistent with agricultural data. *A priori*, both research findings would appear to be relatively more important in the N.A.D. than in the other two divisions. Cyprus Barrel medic has attained widespread use since its release. In 1965 this strain comprised 96 per cent of the 300,000 acres of Barrel medic sown [11]. It is recommended to be sown on alkaline soils. This would appear to favour the Northern

[9] These were: release of Woogenellup subterranean clover, 1958-59; stocking-rate trials showing that commonly-used levels were only half of potential levels; and release of Geraldton strain of subterranean clover, both dated 1959-60.

[10] A list of the research variables is given in Table 6.

TABLE 7

*Estimated Equations: Demand for a Stock of Improved Pastures*
*Lagged Model—Research Variables (i) and (iv)*
*Wheat/Sheep Zone, Western Australia*

| Independent Variables | | Dependent Variable—$ln$(SU) N.A.D. | | C.A.D. | | S.A.D. | |
|---|---|---|---|---|---|---|---|
| Intercept | | 4·24 | | 5·19 | | 5·67 | |
| $ln(P_I/P_P)_{t-1}$ | | 0·34 | n.s. | 0·19 | n.s. | 0·23 | n.s. |
| | | (0·19) | | (0·12) | | (0·14) | |
| RV (i) $_{t-i}$ | $i = 1$ | 0·27 | | 0·22 | | 0·28 | |
| | | (0·08) | | (0·07) | | (0·05) | |
| | 2 | 0·39 | | 0·35 | | 0·35 | |
| | | (0·07) | | (0·04) | | (0·05) | |
| | 3 | 0·38 | | 0·37 | | 0·30 | |
| | | (0·07) | | (0·07) | | (0·05) | |
| | 4 | 0·29 | | 0·30 | | 0·19 | |
| | | (0·08) | | (0·07) | | (0·06) | |
| | 5 | 0·15 | 1·47[a] | 0·18 | 1·42[a] | 0·07 | 1·19[a] |
| | | (0·07) | | (0·06) | | (0·04) | |
| | 6 | 0·03 | n.s. | 0·07 | n.s. | 0·02 | n.s. |
| | | (0·05) | | (0·08) | | (0·04) | |
| RV (iv) $_{t-i}$ | $i = 1$ | 0·50 | | 0·40 | | 0·26 | |
| | | (0·14) | | (0·09) | | (0·09) | |
| | 2 | 0·37 | | 0·21 | 0·61[a] | 0·17 | 0·43[a] |
| | | (0·07) | | (0·07) | | (0·04) | |
| | 3 | 0·20 | | 0·09 | n.s. | 0·05 | n.s. |
| | | (0·13) | | (0·08) | | (0·08) | |
| | 4 | 0·22 | | | | | |
| | | (0·13) | | | | | |
| | 5 | 0·26 | 1·55[a] | | | | |
| | | (0·16) | | | | | |
| | 6 | −0·22 | n.s. | | | | |
| | | (0·28) | | | | | |
| $\bar{R}^2$ | | 0·97 | | 0·98 | | 0·97 | |
| $d$ | | 1·54 | | 1·69 | | 1·55 | |

[a] Sum of significant lag coefficients.
Research Variable (i) = 'Light lands' improvement recommendations, 1946-47.
Research Variable (iv) = Release of Cyprus Barrel medic, 1961-62.

and Central Divisions over the Southern Division [10, Map 2]. The recommended areas for the use of molybdenum in the wheat/sheep zone are predominantly in the Northern and Central Divisions [3]. Farmer response to this finding, as estimated in the lagged model, was large and swift. According to data on fertilizer use, the consumption of molybdenum trioxide in W.A. increased by 550 per cent between 1965 and 1967[8].

In none of the equations shown is the coefficient on the price variable significant. However, the results do suggest that fertilizer demand is very inelastic. The rate of return on research has been calculated only for the whole wheat/sheep zone, using equation (iv) in Table 6. The alternative time-trend model gave a similar value for the price elasticity as estimated in this equation. Details of the gross benefits stream yielded

TABLE 8

*Estimated Equations: Demand for a Stock of Improved Pastures Lagged Model—Research Variables (i) and (v) Wheat/Sheep Zone, Western Australia*

| Independent Variables | | Dependent Variable—$ln$(SU) N.A.D. | C.A.D. | S.A.D. |
|---|---|---|---|---|
| Intercept | | 4·55 | 5·47 | 5·97 |
| $ln(P_I/P_P)_{t-1}$ | | −0·03 n.s. | −0·12 n.s. | −0·08 n.s. |
| | | (0·29) | (0·15) | (0·16) |
| RV (i) $_{t-i}$ | $i=1$ | 0·22 | 0·17 | 0·22 |
| | | (0·13) | (0·07) | (0·07) |
| | 2 | 0·30 | 0·28 | 0·26 |
| | | (0·11) | (0·06) | (0·07) |
| | 3 | 0·29 | 0·30 | 0·20 0·68[a] |
| | | (0·11) | (0·06) | (0·07) |
| | 4 | 0·20 1·01[a] | 0·25 | 0·11 n.s. |
| | | (0·13) | (0·07) | (0·07) |
| | 5 | 0·10 n.s. | 0·14 1·15[a] | |
| | | (0·11) | (0·06) | |
| | 6 | | 0·03 n.s. | |
| | | | (0·05) | |
| RV (v) $_{t-i}$ | $i=1$ | 0·77 | 0·45 | 0·30 |
| | | (0·21) | (0·11) | (0·11) |
| | 2 | 0·66 1·43[a] | 0·30 0·75[a] | 0·19 0·50[a] |
| | | (0·19) | (0·07) | (0·07) |
| | 3 | 0·13 n.s. | 0·03 n.s. | 0·01 n.s. |
| | | (0·28) | (0·13) | (0·14) |
| $\bar{R}^2$ | | 0·92 | 0·96 | 0·94 |
| $d$ | | 1·06 | 1·05 | 1·06 |

[a] Sum of significant lag coefficients.
Research Variable (i) = 'Light lands' improvement recommendations, 1946-47.
Research Variable (v) = Molybdenum deficiency on 'light lands', 1965-66.

by each of the successful research findings up to 1967-68 is presented in Table 9.

Various internal rates of return were calculated as follows:

(i) The stream of benefits from research variables (i) and (ii) were combined, on the basis that both findings came from research at the W.A. Department of Agriculture's Wongan Hills Research Station. Research costs were estimated at two scientists per year from 1935-36 to 1945-46, and three scientists per year from 1946-47 to 1955-56. These costs were assumed to include some expenditure by the W.A. Institute of Agriculture which co-operated on the clover-ley studies. The internal rate of return on this cost stream was approximately 53 per cent.

(ii) The Department of Agriculture was solely involved in the molybdenum studies—research variable (v). Research costs on this project were estimated at two scientists per year for the period 1960-61 to 1967-68. The internal rate of return calculated for this project alone was 86 per cent.

(iii) The gross benefit streams estimated for all significant research

TABLE 9

*Gross Benefits Estimated for Successful Pasture Research Wheat/Sheep Zone, Western Australia*

| Research Variables | Annual Gross Benefits | From | To | Total Gross Benefits to 1967-68 |
|---|---|---|---|---|
| | ($) | | | ($) |
| (i) | 634,890 | 1947-48 | 1967-68 | 13,332,690 |
| (ii) | 380,073 | 1951-52 | 1967-68 | 6,461,241 |
| (iii) | 357,487 | 1957-58 | 1967-68 | 3,932,137 |
| (iv) | 134,548 | 1962-63 | 1967-68 | 807,288 |
| (v) | 330,434 | 1966-67 | 1967-68 | 660,868 |
| Total | | | | 25,114,220 |

Research Variables— (i) Improvement recommendations for 'light lands', 1946-47.
(ii) Clover-ley farming system for 'light lands', 1950-51.
(iii) Lime-pelleting of legume seeds, 1956-57.
(iv) Release of Cyprus Barrel medic, 1962-63.
(v) Molybdenum deficiency of 'light lands', 1965-66.

variables were added together and the internal rate of return for total pasture research costs was calculated, giving a figure of approximately 48 per cent.

## *Discussion of Results*

Briefly, some results from the study were:

1. The important pasture research findings in the three regions examined were predominantly in the field of plant nutrition.
2. Estimated internal rates of return on important research findings were very high, consequently the average rate of return on pasture research in the post-war period has probably also been very high. There were, however, substantial differences between regions.
3. The adoption lags, as measured in this study, were shown to be very short. The image of the farmer as unresponsive to technological change needs to be questioned.
4. Lags in adjustment of the stock of improved pastures to changes in prices were also very short.

Owing to the high degree of collinearity between the real and the relative price variables it was generally impossible to separate the effects of the two. Therefore, no firm conclusions could be drawn about the role which factor substitution between land and improved pastures has played in the demand for improved pastures. It should also be remembered that because the effects of these two variables could not be separated, the coefficients estimated on the real price variable are probably overstated.

By estimating the input-demand function in double-log form the detection of any change over time in the price elasticity of demand is foregone; the assumption here was that the coefficient is constant through time. In their linear estimations, Metcalf and Cowling [9] found that the elasticity of demand for fertilizers in the United Kingdom fell from —1·2 in 1948 to —0·6 in 1965.

Almon [1] suggests two criteria for the choice of the *length* of the preferred polynomial distributed lag—the $R^2$, and the time at which stability in the lag is reached. However, the subjectiveness of deciding on the preferred lags, especially where a number of lags were estimated in the one equation, should not be understated. The difficulty is increased when there appears to be interdependence between research variables. For instance, taking the case of the Southern Tablelands, in the absence of the other significant research variable, the sum of lag coefficients on the included variable is much larger than when both are included in the equation. One explanation for this is that the findings about lime pelleting increased the value of the previous findings on the role of molybdenum.

As distinct from the usual sociological approach of measuring the adoption lag as the *numbers* of farmers adopting a new practice over time, the purpose here has been to differentiate between those changes in demand for improved pastures which are a function of changes in price, and those which are a function of shifts in the production function. The former is captured by the price variable, the latter by the research variables. It should be pointed out that the model does not distinguish between practices adopted following a change in price. It is contended, however, that the adoption 'tail' measured in sociological studies is explainable in terms other than the slow response of farmers to new-technology.

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